Geotechnical mechanisms of roof fall ahead of face support in longwall mining

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Abstract. Longwall mining is one of the most productive methods for extracting underground coal seams. Although the understanding of longwall mining-associated geotechnical mechanisms has been significantly improved that contributes to better ground control, roof rock/top coal fall ahead of support (roof fall) has not been fully understood that causes severe damage to equipment and casualty at face. Empirical, theoretical and modelling methods were successfully used in past studies to understand the mechanisms driving roof fall; however, key mechanisms and their interactions during the fall were not satisfactorily investigated due to limitation of each method. This study aims to gain a systematic understanding of roof fall mechanisms in longwall operation. A review of past studies on roof fall is implemented with emphasis on the principles of applied research methods. The study confirms that the interaction between roof strata, coal seam and face support largely controls roof fall while numerical modelling shows great potential in studying roof fall complex mechanisms. The paper's findings provide mining engineers/scientists with a systematic understanding on roof fall from which more effective roof control strategies can be further developed.

1. Introduction

Longwall mining is one of the most productive methods for extracting underground coal seams in many countries such as China, Australia, Poland and Vietnam [1-3]. Although longwall mining technology has been significantly improved from manual by using blasting and hydraulic prop to mechanised by using shearer and self-advanced support, the roof rock or top coal between coal face and support may suddenly fall that causes severe damage to equipment and casualty. This geotechnical problem is ranked to be critical and thus has been studied by mining companies and researchers.

In order to develop sound engineering solutions to roof fall, many scientific works have been implemented to understand the mechanisms and parameters controlling the phenomenon in different geo-mining conditions. Various researching methods such as empirical, theoretical and modelling were successfully applied in past studies; however, due to intrinsic limitation of each method, key mechanisms driving roof fall and their interactions during the fall have not been satisfactorily investigated. This partly results in the fact that there is no single measure to roof fall that is universally applied at present.

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The paper's content presents a review of past studies on roof fall with emphasis on the principles of applied research methods. The scientific works and reports from coal operation companies in China, Australia, Poland and Vietnam are discussed that cover most types of longwall technology. The paper's findings provide mining engineers/scientists with a systematic understanding on roof fall from which more effective roof control strategies can be further developed.

2. Roof fall mechanism from longwall face in China

According to Bai et at. [4], nearly 50% of the deadly incidents in 2012 resulted from roof falls in longwall faces or roadways that killed 459 workers in China. They reported that more than half of the longwall face roof fall originated from coal wall spall and then proposed a conceptual model of the roof fall and coal wall spall, as illustrated in Fig. 1. Working on the geo-mining conditions of the caving longwall No. 14101 at Mjialiang coal mine, Bai et al. [5] and Bai et al. [4] used continuum modelling as the main tool for analysis of coal wall spall. In particular, a Finite Difference Method-based code was used to successfully find out that coal wall presents a brittle failure mode; failure mode and failure depth are dominated by the shear failure bands that develop from the down and upper corners of coal face; and failure shape is dependent on the geometrical system of discontinuities in coal seam (Fig. 2). In addition, some support characteristics controlling the fall were outlined, which are the setting resistance, advance lag and face guard.

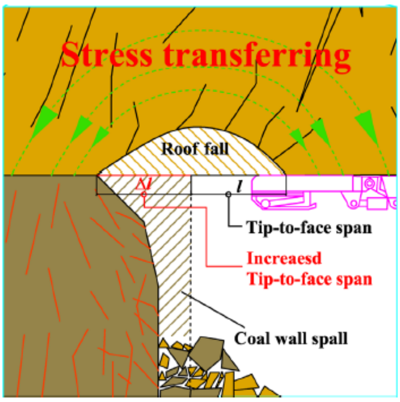

Fig. 1. Conceptual model of roof fall and coal wall spall at longwall face (modified after Bai et al. [4]).

A series of theoretical studies on coal wall spall was reviewed and presented in Bai et al. [6]. Note that these studies are in Chinese and their English translations are not available. The authors stated that in most of the previous studies, coal wall was regarded as an isolated object and the impacts of roof strata, shield support and face guard on coal wall stability were ignored. The authors then based on torque equilibrium to develop a mechanics model incorporating coal wall, roof strata and shield support. Compared to the above numerical studies, this study analysed the role of not only support characteristics but also fractured roof and mining height in coal wall failure, as shown in Fig. 3.

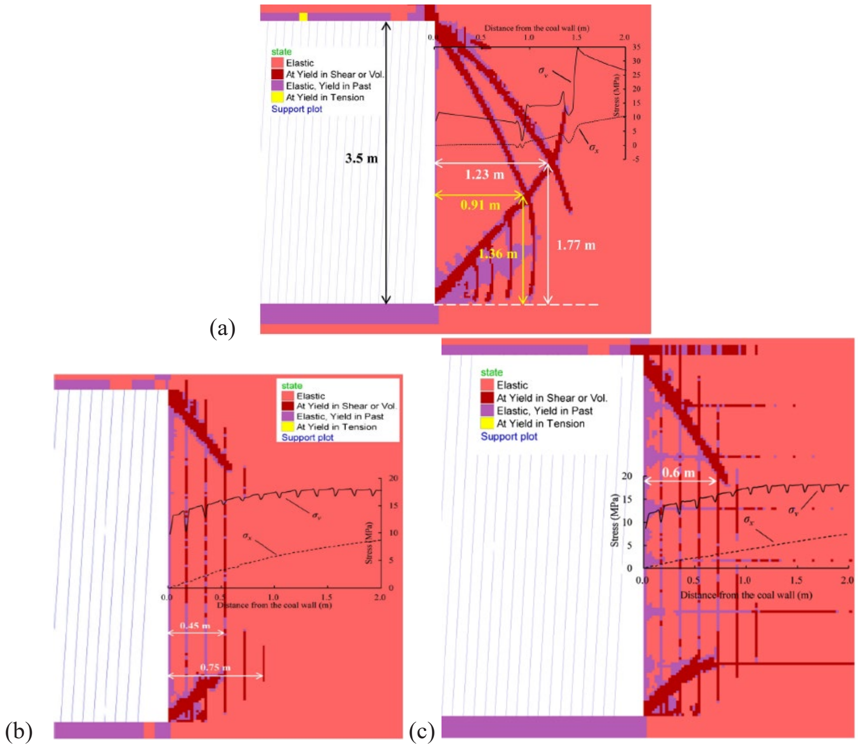

Fig. 2. Coal wall failure with (a) no discontinuities, (b) vertical discontinuities and (c) cross-discontinuities in a continuum-based model (modified after Bai et al. [5]).

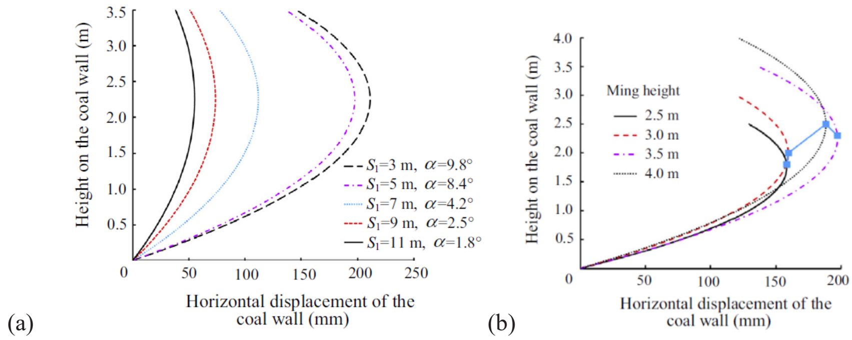

Fig. 3. Relationship between (a) fracture position in main roof and coal face horizontal displacement, and (b) mining height and coal face horizontal displacement [6].

Apart from continuum modelling, discontinuum methods were used in a few coal wall stability studies. By using a discontinuum-based model (Fig. 4), Wang et al. [7] concluded that improving support capacity, cohesion of coal mass and decreasing roof load on coal face are the key to improve coal face stability. Similarly, Yao et al. [8] stated that although tensile fracture dominates the failure in both horizontal and up-dip coal faces, the difference lies in their failure forms: failure is arc-shaped in horizontal faces and V-shaped in up-dip faces. In contrast, the down-dip coal face and its roof are vulnerable to shear failure due to large areas of shear fractures inside the face. The authors also emphasised that depth of coal face, mining height, panel advance velocity and seam strength are driving factors of the spall.

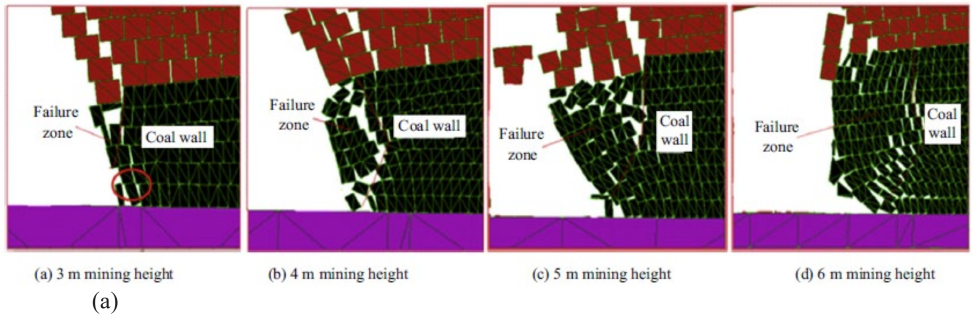

Fig. 4. Distribution of coal face failure zone at different mining heights in a discontinuum-based model [7].

3. Roof fall mechanism from longwall face in Australia

Based on a program of intensive hydraulic support monitoring in various Australia mining conditions, Frith et al. [9] stated that the roof stability between the face and canopy tip is one longwall face problem that is not only affected by face spall but also more importantly, the amount of roof convergence during mining cycles. The authors found that the likelihood of a roof fall is directly related to the heavily stresses area and the strength and structure of roof strata, as illustrated in Fig. 5. The relationship between roof fall and roof convergence was further validated against the field measurements implemented by Medhurst [10]. This author also outlined key factors driving the fall, which are setting load of support, strength of roof strata, tip-to-face roof span and support capacity.

Using site experience from one mine at Bowen Basin, Queensland over 10 years of longwall production, Payne [11] concluded that weak roof (less than 10 MPa in the bolted horizon) was the main roof control problem at the site. Furthermore, weak and highly cleated coal, water inflow from overlying aquifers, some minor structures, and a diatreme in the main headings have also contributed to the challenges at the mine. In an extreme case, weak roof combined with friable weak coal is particularly prone to roof fall when production slows due to delay or preparation for longwall take-off.

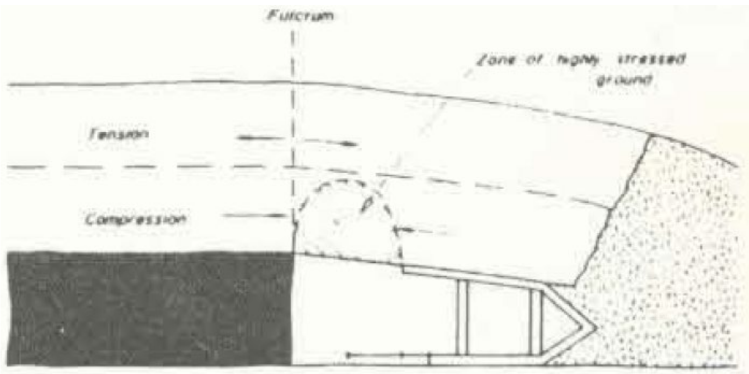

Fig. 5. Cantilevering action of strata resulting in highly stresses immediate roof [9].

4. Roof fall mechanism from longwall face in Poland

In Poland, longwall method is the main mining system used for hard coal mines. Difficult mining conditions such as deep mining, previous mining activities and rock mass tremors result in minor and massive roof falls in longwall faces as stated by Prusek et al. [12]. The author determined seven parameters controlling roof fall (i.e., low self-supporting ability of first roof strata; massive roof layers overhanging behind shield line; distribution of support capacity along canopy length; low bearing capacity of immediate floor strata; face orientation in relation to roof strata joints' direction; face line orientation to faults; longwall inclination) before developing a new method for assessing the risk of roof fall (Fig. 6). It is noted that since the method was mainly based on empirical and expert techniques, the geotechnical mechanisms associated with roof fall were not considered in the assessment.

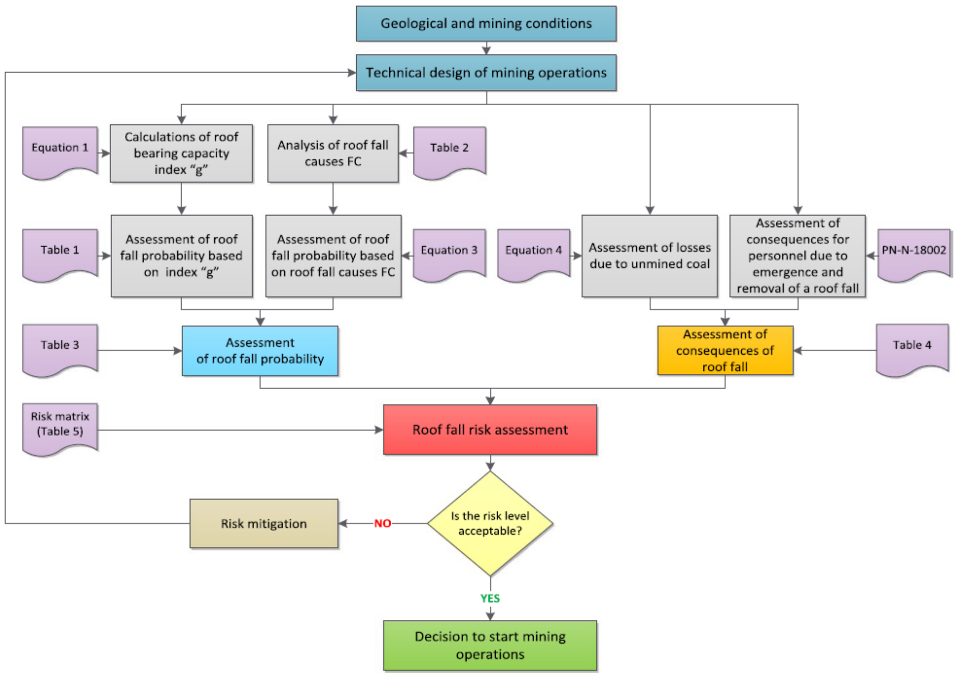

Fig. 6. Support VINAALTA 2.0/3.15 and shearer MB 12-2V2P/R-450E applied at Vang Danh coal mine in period of 2008–2012. Algorithm for assessing roof fall risk in caving longwall [12].

5. Roof fall mechanism from longwall face in Vietnam

Roof fall ahead of support in longwall face has been reported in Vietnam coal industry for a long time but only in recent years the problem has been studied in mechanised longwalls. Vu and Do [13] theoretically analysed the impacts of mine pressure, geological condition, unsupported span of roof, face advance rate, and setting load and unloading of support on coal wall spall and roof fall before proposing some technical measures to the problem. Based on on-site experience when dealing with roof fall in the world, Dao [14] analysed the influence of geological parameters on roof fall and proposed some reinforced solutions to weak coal/rock in accordance with Quang Ninh mining condition. More recent works [15-17] focused on the relationship between coal cohesion and coal moisture based on which a practical solution such as water/chemical injection was developed. A trial application was conducted at longwall 14-5-11 by using Erkadol-K/Erkadur chemical made in Poland, as shown in Fig. 7.

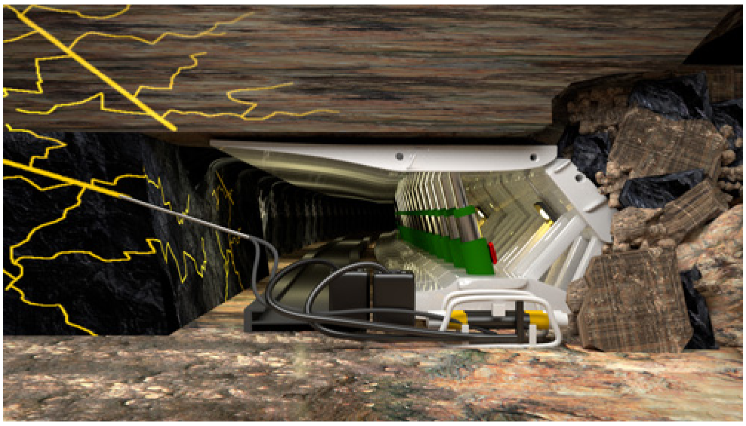

Fig. 7. Chemical injection to prevent coal wall spall and roof fall [18].

6. Discussion and Conclusions

Industrial reports from major coal industries such as China and Australia have outlined that roof fall ahead of face support is basically related to the roof convergence rate and/or coal wall spall. This explains why several investigations (e.g., Chinese and Vietnamese studies) have focused on coal wall spall problem to gain insight into roof fall. Theoretical, empirical and field measurement methods were implemented to successfully determine major causes of the spall/fall in past studies; however, the internal mechanisms during the fall could not be represented nor analysed. Alternatively, numerical methods were successfully used to investigate roof failure and roof fall mechanisms. The continuum methods realistically simulated stress change, material failure mode and coal seam deformation when the fall occurred. Nevertheless, due to the continuum medium of modelling, the investigations could only indirectly study the complete detachment of coal/rock material. Unlike continuum methods, discontinuum methods are capable of modelling the complete detachment in the fall. It is important to note that unrealistic interaction between intact material failure and discontinuity failure is always a challenging issue in plastic-discontinuum model. A solution to this issue has recently proposed in Le et al. [19].

Based on scientific works and reports from China, Australia, Poland and Vietnam coal industries, this paper confirms that roof stability between coal wall and face support is simultaneously controlled by coal seam, roof strata and support characteristics. Numerical modelling is capable of representing material failure and fall mechanisms in different geo-mining conditions; therefore, they show great potential application in studying roof fall. The paper's findings provide mining engineers/scientists with a systematic understanding on roof fall from which more effective roof control strategies can be further developed.

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